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The value of simplicity: externally validating the Baylor cranial gunshot wound prognosis score

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Abstract

OBJECTIVE—Gunshot wounds to the head (GSWH) are devastating injuries with a grim prognosis. Several prognostic scores have been created to estimate mortality and functional outcome, including the so-called Baylor score, an uncomplicated scoring method based on bullet trajectory, patient age, and neurological status on admission. This study aimed to validate the Baylor score within a temporally, institutionally, and geographically distinct patient population.

METHODS—Data were obtained from the trauma registry at a level I trauma center in the southeastern US. Patients with a GSWH in which dural penetration occurred were identified from data collected between January 1, 2009, and June 30, 2019. Patient demographics, medical history, bullet trajectory, intent of GSWH (e.g., suicide), admission vital signs, Glasgow Coma Scale score, pupillary response, laboratory studies, and imaging reports were collected. The Baylor score was calculated directly by using its clinical components. The ability of the Baylor score to predict mortality and good functional outcome (Glasgow Outcome Scale score 4 or 5) was assessed using

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the receiver operating characteristic curve and the area under the curve (AUC) as a measure of performance.

RESULTS—A total of 297 patients met inclusion criteria (mean age 38.0 [SD 15.7] years, 73.4% White, 85.2% male). A total of 205 (69.0%) patients died, whereas 69 (23.2%) patients had good functional outcome. Overall, the Baylor score showed excellent discrimination of mortality (AUC = 0.88) and good functional outcome (AUC = 0.90). Baylor scores of 3–5 underestimated mortality. Baylor scores of 0, 1, and 2 underestimated good functional outcome.

CONCLUSIONS—The Baylor score is an accurate and easy-to-use prognostic scoring tool that demonstrated relatively stable performance in a distinct cohort between 2009 and 2019. In the current era of trauma management, providers may continue to use the score at the point of admission to guide family counseling and to direct investment of healthcare resources.

Keywords

gunshot wound; penetrating brain injury; prognostic scores; trauma; traumatic brain injury

Civilian gunshot wounds to the head (GSWH) account for the largest proportion of deaths from traumatic brain injury in the US, with approximately 20,000 cases annually.[1] Prognosis is grim, with only 10% of patients surviving to hospital arrival, and only 50% of these patients surviving the initial emergency department (ED)resuscitation.[2]Goals of care during the inpatient stay involve optimizing survival and functional outcome. To as-sist in clinical decision-making for GSWH goals, several predictors and treatment paradigms have been identified.[3–8]

In 2014, the group at the Baylor College of Medicine published a prognostic scoring system[9] that was developed to predict both survival and Glasgow Outcome Scale (GOS) score[10,11] at 6 months by using the features of bullet trajectory, patient age, and neurological status on admission (measured by Glasgow Coma Scale [GCS] score and pupillary response). This so-called Baylor score is attractive given a limited number of variables (N = 4) and ease of use as compared to other more complicated algorithms that have been published since.[12–15] Despite its utility and ease of use, this score has not been externally validated. Furthermore, the score was developed with patients managed between 1990 and 2008, which may limit its utility given present-day resuscitation strategies.

In the last decade, there have been considerable evidence-based improvements in trauma management, including massive transfusion protocols,[16,17] standardized resuscitation ratios,[18] robust training and simulation programs, integrated systems of care,[19] and concentration of care to level I trauma centers.[20–22] Hence, we sought to validate the Baylor GSWH prognostic score within a distinct population treated during this current era of acute trauma management. We hypothesized that the Baylor score used at admission would accurately predict survival to hospital discharge, as well as functional outcome at follow-up in a modern GSWH cohort.

Methods

Study Design

Data were obtained for a retrospective cohort study from a prospectively collected trauma registry that contains all patient admissions for which either a trauma activation or admission to trauma surgery occurred at Vanderbilt University Medical Center, a large level I trauma center in the southeastern US. The study was approved by the institutional review board, and data accession and storage were performed in accordance with the Health Insurance Portability and Accountability Act (HIPAA).

Patients were selected from the trauma registry if they were admitted to our institution for GSWH with dural penetration—as identified by CT scan of the head—between January 1, 2009, and June 30, 2019. No patients meeting these criteria were excluded. As such, the cohort used for this study consisted of patients with GSWH who were institutionally, geographically, and temporally distinct from the 1990–2008 cohort treated at Ben Taub General Hospital, which was used to develop the Baylor score.[9] Patient records were manually reviewed.

Standard Clinical Management

Acute trauma management was performed in accordance with up-to-date advanced trauma life support and current resuscitation guidelines.[23,24] Management of traumatic brain injury was largely in accordance with Brain Trauma Foundation guidelines,[25] including the following: 1) intracranial pressure (ICP) was monitored when there was no clear mass lesion requiring evacuation and the GCS score was 8 or below; 2) hyperosmolar therapy of 3% saline was administered as boluses and continuous intravenous infusion, titrated to an ICP < 20 mm Hg with a maximum serum sodium concentration of 155 mEq/L; and 3) decompressive craniectomy was performed for unilateral lesions with mass effect and correlated neurological deficits or medically refractory increases in ICP.

Central venous catheters and arterial lines were placed routinely as indicated. It was institutional practice to place an external ventricular drain (EVD) as the method of ICP monitoring when ventricular size was appropriate, and to place an ICP monitor secondarily if the EVD failed or if there was no accessible ventricle. Patients with coagulopathy received platelet transfusions for a goal of 100,000 platelets/μl, and fresh-frozen plasma or prothrombin complex concentrate was administered to maintain an international normalized ratio (INR) < 1.7. If the injury was thought to be nonsurvivable, as assessed by trauma and neurosurgery attending physicians' review of imaging and physical examination, consideration was given to shift care toward end-of-life decision-making or cardiovascular support for organ donation. In contrast to the institutional practice reported in the development of the Baylor score,[9] there was no minimum amount of time required prior to allowing the patient's surrogate decision-maker to request palliative extubation or comfort care. Notably, the Baylor score was not officially adopted by the institution in the current study in any capacity for prognostic or care-directing purposes following publication in 2014.[9]

Variables

Variables collected from patient charts included demographics, medical history, bullet trajectory, intent of injury (e.g., suicide), admission vital signs, GCS score on admission, pupillary response on admission, laboratory studies, and imaging reports. Bullet trajectories were grouped into 4 categories in accordance with prior literature:[9,12] 1) unihemispheric or bifrontal, 2) bihemispheric, 3) posterior fossa, or 4) transventricular. The Baylor score was calculated with these variables according to the following formula: (if age > 35 years, then +1) + (if GCS score = 3 or 4, then +1) + (if nonreactive pupils bilaterally, then +1) + (if bullet trajectory posterior fossa or bihemispheric, then +2).[9] Total scores range from 0 to 5, with higher scores associated with worse outcomes. The outcomes predicted by each score as published by Gressot et al. are in Table 1.[9]

Outcomes

The primary outcome was in-hospital mortality, and the secondary outcome was functional outcome at last follow-up. Recorded history and physical examination at last follow-up were interpreted to assign a GOS score from 1 to 5, where 1 corresponds to death, 2 corresponds to neurovegetative state, 3 corresponds to severe disability dependent on daily support, 4 corresponds to moderate disability but independence in daily life, and 5 corresponds to normal life with minor neurological deficits.[11] In accordance with prior literature, a good functional outcome was defined as a GOS score of 4 or 5 at the last follow-up visit.[9]

Statistical Analysis

Categorical variables are presented as frequency and proportion. Continuous variables are presented as mean (SD). Continuous variables with nonnormal distributions are presented as median (interquartile range [IQR]). Expected outcomes were based on calculated Baylor score as detailed above. For analysis, scores were grouped based on the original groupings by Gressot et al.[9] For in-hospital mortality, scores were grouped as 0–1, 2, and 3–5. For functional outcome, scores were grouped as 0, 1, 2, and 3–5 (Table 1). Observed outcomes within the patient population were stratified by year and plotted. Nonparametric receiver operating characteristic (ROC) curves and calibration plots were created separately for mortality and good functional outcome. The area under the curve (AUC) was calculated from each ROC curve to assess degree of discrimination. Analyses were performed in Stata IC version 16.1 (StataCorp).

Results

Baseline Characteristics

A total of 297 patients met the inclusion criteria (mean age 38.0 [SD 15.7] years, 73.4% White, 85.2% male). The intent of injury was most often suicide (n = 182; 61.3%). The majority had a poor neurological examination on arrival—177 (59.6%) patients had nonreactive pupils and 227 (76.4%) patients had a GCS score of 3 or 4. Demographic and admission variables are presented in Table 2. In com parison to the study population used to develop the Baylor score, our cohort generally had older age (median [total range] 35 [18–80] years vs 26 [12–73] years); an increased proportion of White patients (73% vs

22%); and a greater proportion of patients with a poor GCS score of 3 or 4 (76% vs 46%) (Supplementary Table 1).9 The Baylor score was 0 for 28 (9.4%) patients, 1 for 40 (13.5%) patients, 2 for 67 (22.6%) patients, 3 for 29 (9.8%) patients, 4 for 72 (24.2%) patients, and 5 for 61 (20.5%) patients. Mortality and good outcome rates for each score are displayed in Table 1 and Fig. 1. A total of 205 (69.0%) patients died in the hospital, whereas 69 (23.2%) patients had a good long-term functional outcome of GOS score of 4 or 5. No patients with a Baylor score of 4 or 5 had a good functional outcome (Fig. 1). The median time to follow-up visit was 116 (IQR 27–384) days (Table 3).

Primary Outcome: In-Hospital Mortality

Across each year from 2009 to 2019, patients with Baylor scores of 3–5 showed higher than expected true mortality rates. For Baylor scores of 0–1 and 2, observed mortality approached expected values (Fig. 2). The ROC curve of the Baylor score with mortality revealed an AUC of 0.88, exhibiting excellent discrimination (Fig. 3A). A calibration plot revealed that Baylor scores of 3–5 underestimated true mortality (Fig. 3B).

Secondary Outcome: Functional Outcome

Across each year in the study period, patients with Baylor scores of 0 and 1 encountered better than expected rates of good functional outcome. Patients with Baylor scores of 3–5 showed similar to expected rates of good functional outcome (Fig. 4). The ROC curve of the Baylor score with good functional outcome revealed an AUC of 0.90, indicating excellent discrimination (Fig. 3C). A calibration plot showed that Baylor scores of 0, 1, and 2 underestimated the true rate of good functional outcome, whereas scores of 3–5 were an adequate approximation (Fig. 3D).

Discussion

This study sought to externally validate the Baylor score for use in the modern era of trauma management among a distinct population of patients with GSWH that was twice the size of the score-determining study from 2009 to 2019. We hypothesized that despite marked advance ments in trauma resuscitation and systems of care, the primary prognostic features of age, bullet trajectory, and neurological status at admission would remain predictive of in-hospital mortality and long-term functional outcome. This hypothesis was confirmed by the demonstration that Baylor scores were consistently accurate estimates of true outcome over the 10-year period. To our knowledge, this is the first external validation of the Baylor score, and the results demonstrate that the score is an accurate prognostic tool that can be rapidly applied at the time of admission for patients with GSWH. To address the fact that the original publication introducing the Baylor score was lacking validation and was limited in its small sample size covering a nearly 20-year study period, the current study externally validates the scoring framework and provides support to trauma and neurosurgical teams to use the score, shifting it from academic to clinical relevance.

The utility and accuracy of the Baylor score may be compared against other GSWH prognostic tools. The Surviving Penetrating Injury to the Brain (SPIN) score, published in 2016 and validated to predict survival, is another prognostic score that incorporates the Baylor score components with the additional features of sex, Injury Severity Score, INR, transfer status, and suicidal intent.[12,13] These features are converted into a score in the range of 4–52, which demonstrates potentially improved accuracy for survival prediction, supported by an AUC of 0.97 in the development cohort and 0.88 in the validation cohort.[12,13] Although the SPIN score adds granularity to the estimation of GSWH mortality, there are important limitations to its utility in the clinical setting. Primarily, it is not validated to predict long-term functional outcome, which is an increasingly important target for GSWH treatments.[7,26] Furthermore, it has limited ease of use because of its numerous variables, which can each hold varying levels of weight ranging from 0 to 12. The complicated nature of the score makes it difficult to implement quickly in the clinical setting. In addition to scoring systems, several studies have proposed treatment algorithms to identify patients who would benefit from early aggressive treatment such as resuscitation, decompressive craniectomy, and correction of coagulopathy.[27,28] This guidance serves a useful role in connecting clinical features with recommended treatment decisions, but is limited by a nonquantified structure. By contrast, the Baylor score accurately quantifies GSWH prognosis through an easy-to-use formula consisting of 4 variables.

Although the Baylor score offers an easy-to-use, accurate estimation of GSWH prognosis, it is important to note its limitations. First, although it may offer a concrete value that can be shared with surrogate decision-makers, it should not be used as a definite judgment of patient prognosis for the purposes of palliation or end-of-life decision-making. Second, the Baylor score estimates prognosis at the time of ED arrival, but a patient’s prognosis may change considerably during an inpatient stay. Factors influencing long-term prognosis may change after the acute phase and ED management.2 In particular, the effect of patient survival through initial ED management and resuscitation may be a significant positive prognostic indicator. Future studies may evaluate how the accuracy of the Baylor score evolves over the course of a hospital stay.

Limitations

Because this was a retrospective study, there was limited ability to control for the effects of confounding medical conditions, treatment decisions, and protocols. We have outlined the major trauma and neurosurgical management guidelines followed by our institution during the study period to compare with similar studies. However, we recognize the nuanced nature of patient care and that all patients in this study received individualized care based on the judgment of the treating teams. Furthermore, the Baylor score was published in 2014 and therefore may have been incorporated into treatment decisions made by some attending physicians for patients with GSWH in the present study. This could potentially lead to a “self-fulfilling prophecy” bias, in which the scores investigated in this study were driving treatment decisions. However, the inclusion of many patients treated by a wide variety of providers at a distinct institution, which had not formally integrated the score into clinical practice during the study period, mitigates this concern.

The varying time points for outpatient follow-up visit may be an additional source of bias in the measurement of functional outcome, given that the Baylor score was originally developed to predict the 6-month GOS score specifically. The median time to follow-up was greater than 90 days, suggesting less concern for underestimation of neurological recovery. Nevertheless, extended follow up on the order of years would strengthen this outcome measure. Finally, the study population was predominantly White and derived from a single, level I trauma center in the southeastern US. This limits the generalizability of the Baylor score's validity to hospitals in different regions, with different racial and ethnic distributions, and with differing trauma management capability. It should be noted that, although the study population used to develop the Baylor score had pronounced sociodemographic differences from our study cohort, the score remained valid in this analysis (Supplementary Table 1). This finding may suggest an increased generalizability for the Baylor score across socioeconomic distributions. However, possible regional differences in prevalence of self-inflicted GSWH injury,[12,13] as well as institutional differences in end-of-life care management, may limit the generalizability of the Baylor score. A more robust analysis can be performed with data from additional institutions.

Conclusions

Although management of acute trauma has continued to evolve over the past 2 decades, GSWH remain a devastating injury with poor outcomes. The Baylor score is an accurate and easy-to-use prognostic scoring tool that can be applied at admission to predict in-hospital mortality and 90-day functional outcome. This score demonstrates relatively stable performance from 2009 to 2019. Providers may use the Baylor score at the point of admission to guide the counseling of families and direct the investment of surgical and intensive care resources. However, the score must be used with the recognition that prognosis may change during the inpatient course.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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ABBREVIATIONS

AUC	area under the curve
ED	emergency department
EVD	external ventricular drain
GCS	Glasgow Coma Scale
GOS	Glasgow Outcome Scale
GSWH	gunshot wounds to the head

ICP	intracranial pressure
INR	international normalized ratio
IQR	interquartile range
ROC	receiver operating characteristic
SPIN	Surviving Penetrating Injury to the Brain

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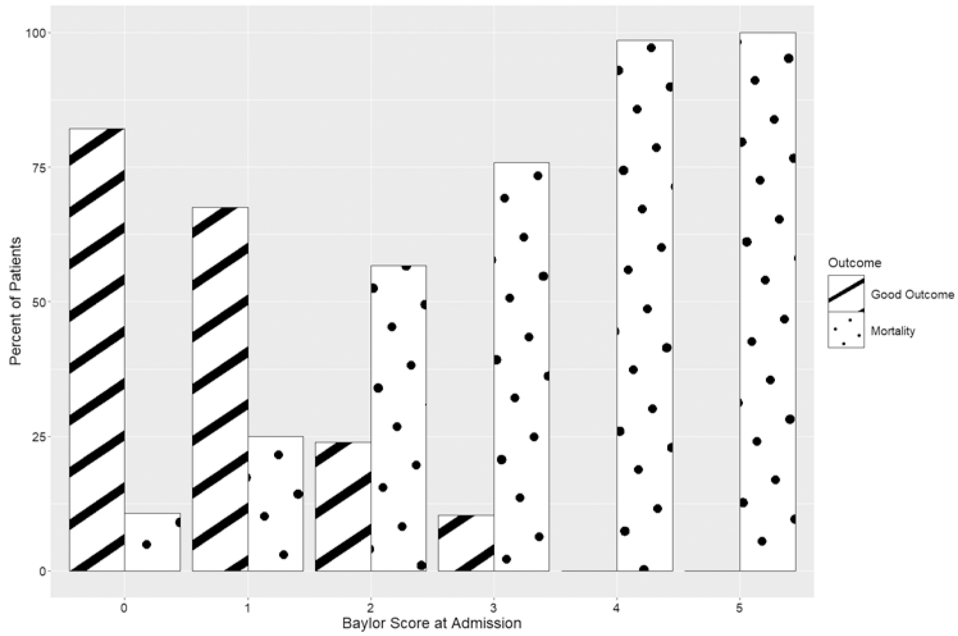

FIG. 1.

Rates of mortality and good functional outcome (GOS score of 4 or 5), segmented by Baylor score.

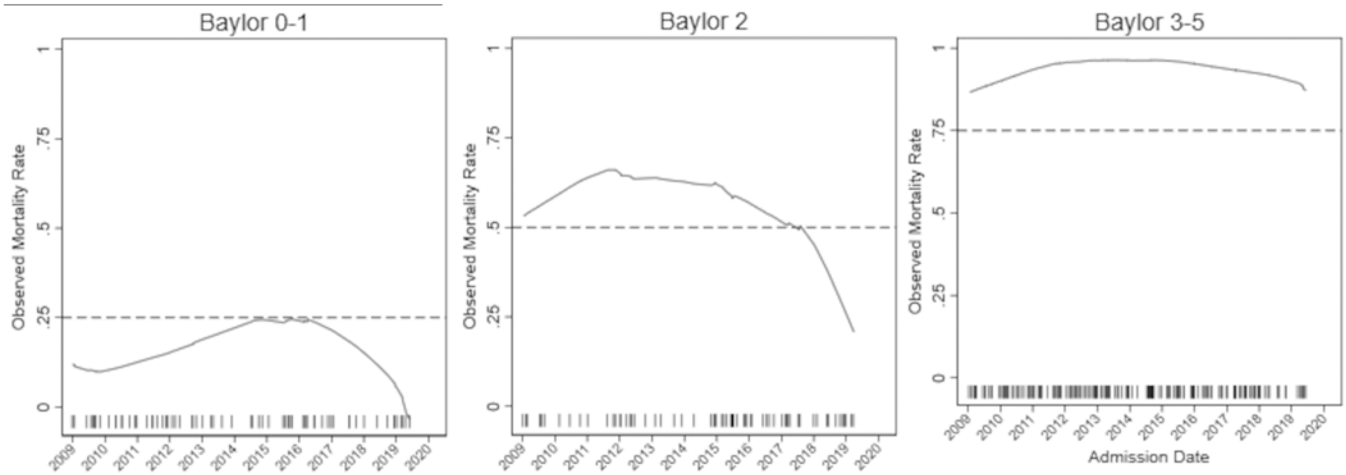

FIG. 2.

Mortality over time, segmented by Baylor score groups. *Dashed reference lines* indicate estimated mortality based on score. A rug plot within each graph indicates the number of observations by admission date. Baylor scores of 3–5 had higher than expected mortality.

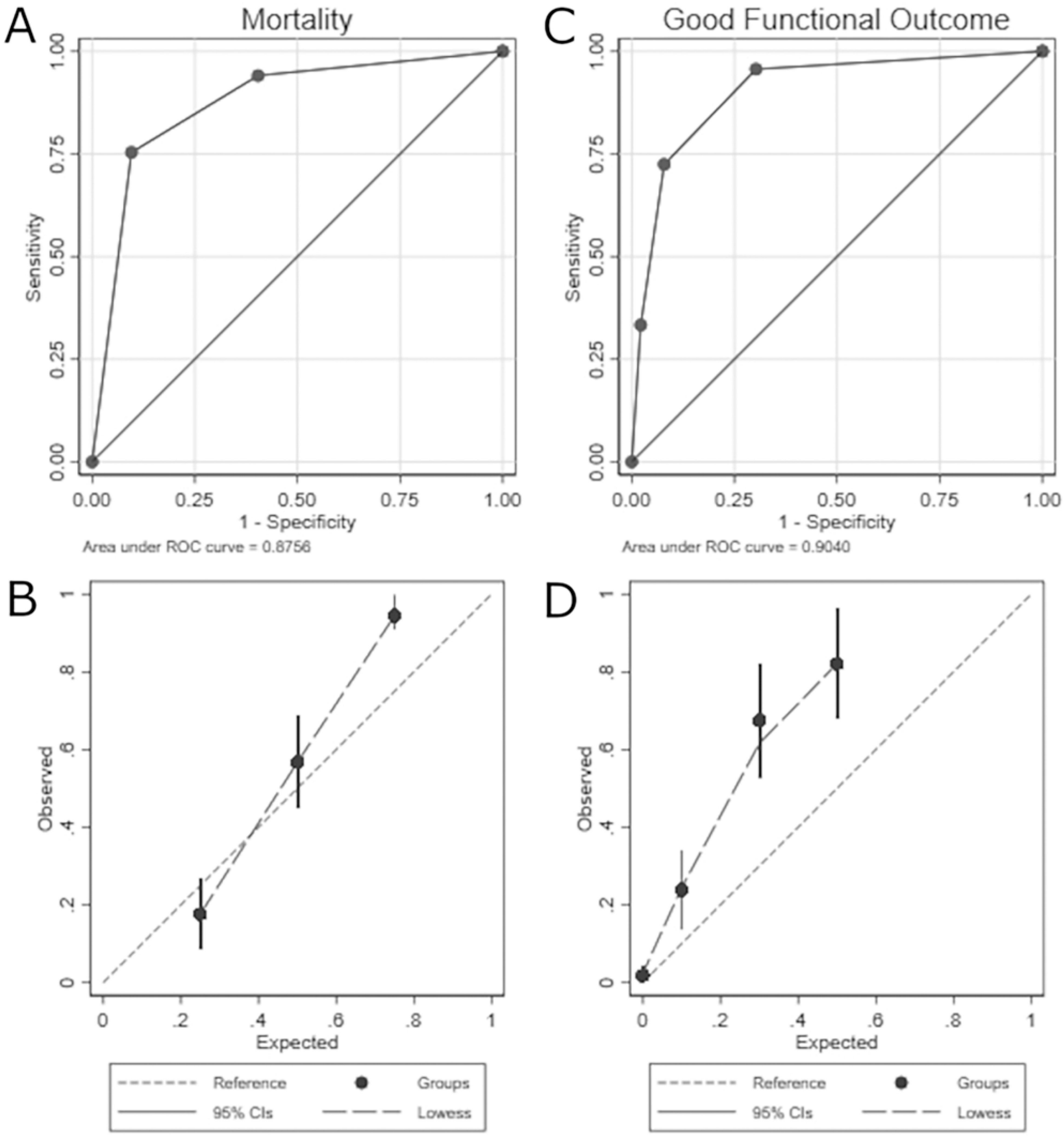

FIG. 3.
A: The Baylor score's prediction of mortality, an ROC curve with calculated AUC. **B:** Calibration curve of Baylor score groups in prediction of mortality, with 95% CIs. Scores of 3–5 show underestimation of mortality. **C:** The Baylor score's prediction of good functional outcome, an ROC curve with calculated AUC. **D:** Calibration curve of Baylor score groups in prediction of good functional outcome, with 95% CIs. Scores of 0, 1, and 2 underestimate probability of good functional outcome. Lowess = locally weighted scatterplot smoothing.

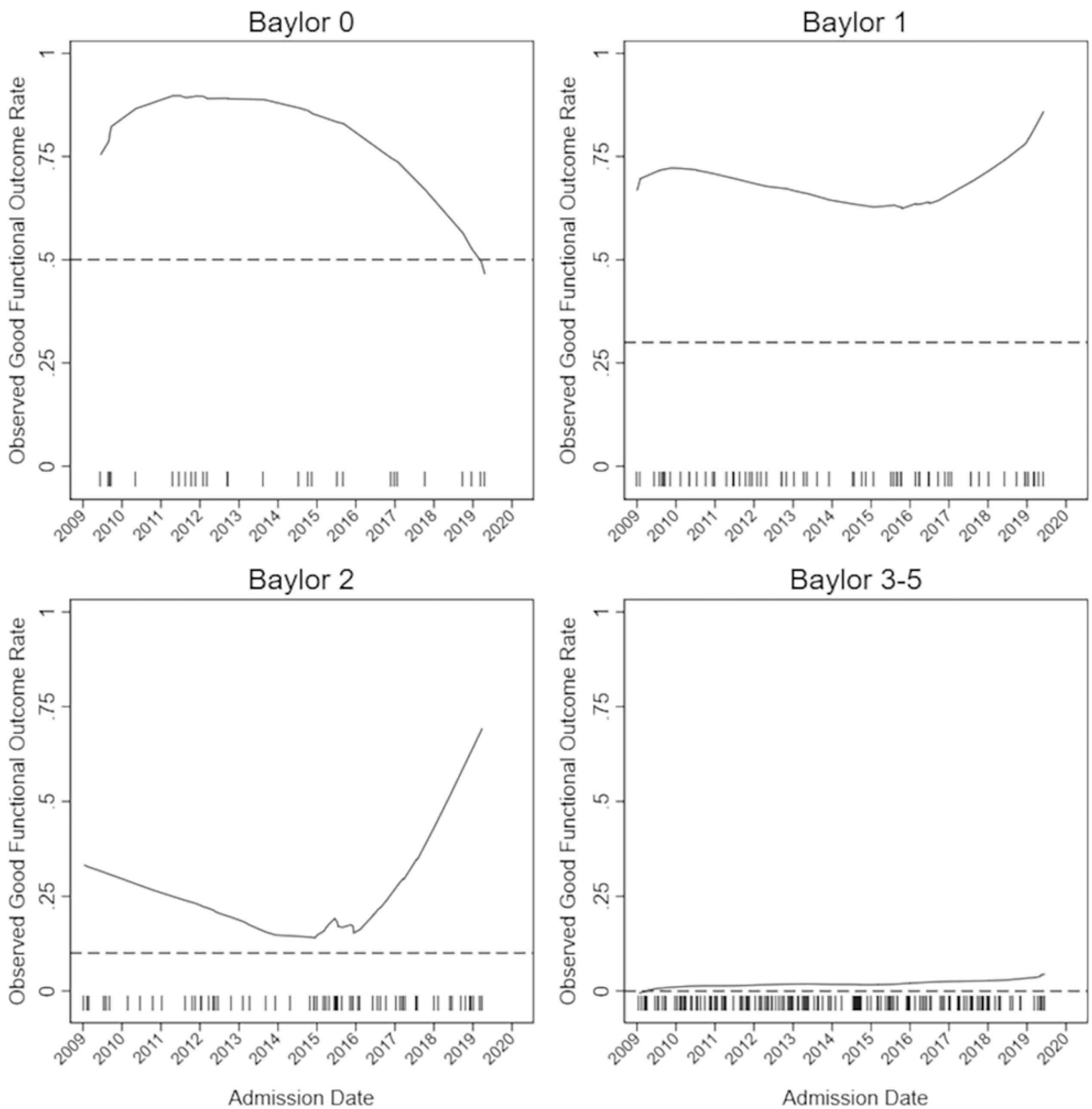

FIG. 4.

Functional outcome over time, segmented by Baylor score groups. *Dashed reference lines* indicate estimated probability of good functional outcome based on score. A rug plot within each graph indicates the number of observations by admission date.

TABLE 1.

Probabilities of mortality and good functional outcome predicted by Baylor score

Baylor Score	Predicted Outcomes at 6 Mos Postinjury		Observed Outcomes	
	Mortality	Good Functional Outcome	Mortality	Good Functional Outcome
0	25%	50%	7%	82%
1		30%	25%	68%
2	50%	10%	57%	24%
3	75%	0%	76%	10%
4			97%	0%
5			100%	0%

Modified with permission from Gressot LV, Chamoun RB, Patel AJ, et al. Predictors of outcome in civilians with gunshot wounds to the head upon presentation. *J Neurosurg.* 2014;121(3):645–652.

TABLE 2.

Demographics and characteristics during admission in 297 patients with GSWH

Variable	Value
Demographics	
Age in yrs, mean (SD)	37.95 (15.72)
Race	
Asian	2 (0.7%)
Black	65 (21.9%)
White	218 (73.4%)
Other	12 (4.0%)
Sex	
Male	253 (85.2%)
Female	44 (14.8%)
Admission variables	
Initial INR, mean (SD)	1.74 (1.51)
MAP in mm Hg, mean (SD)	98.98 (25.40)
Outside hospital transfer	64 (21.5%)
Intent of injury	
Suicide	182 (61.3%)
Homicide	65 (21.9%)
Accidental	14 (4.7%)
Unknown	36 (12.1%)
Injury Severity Score	
<8	0 (0.0%)
9–15	14 (4.7%)
16–24	81 (27.3%)
>24	202 (68.0%)
Midline shift	
Present on CT scan	114 (38.4%)
In mm, mean (SD)	2.68 (4.32)
Bullet trajectory	
Unihemispheric or bifrontal	153 (51.5%)
Bihemispheric	139 (46.8%)
Posterior fossa	17 (5.7%)
Transventricular	47 (15.8%)
GCS score	
3 or 4	227 (76.4%)
5–8	13 (4.4%)
>8	57 (19.2%)
Pupil reactivity	

Variable	Value
None	166 (55.9%)
One	20 (6.7%)
Both	76 (25.6%)
Reactive + globe rupture	22 (7.4%)
Nonreactive + globe rupture	11 (3.7%)
Bilat globe rupture	2 (0.7%)
Baylor score	
0	28 (9.4%)
1	40 (13.5%)
2	67 (22.6%)
3	29 (9.8%)
4	72 (24.2%)
5	61 (20.5%)
Max ICP in mm Hg, mean (SD)	33.36 (25.26)

MAP = mean arterial pressure; max = maximum.

Unless otherwise indicated, values are expressed as the number of patients (%).

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TABLE 3.

Treatments rendered and patient outcomes

Variable	Value
Treatments rendered	297
Craniotomy performed	52 (17.5%)
ICP monitor	14 (4.7%)
EVD	19 (6.4%)
Outcomes	
Death	205 (69.0%)
Length of stay in days, mean (SD)	6.09 (10.02)
ICU length of stay in days, mean (SD)	3.88 (5.07)
Follow-up time in days, median (IQR)	116 (26.6, 384.3)
GOS score	
1	205 (69.0%)
2	0 (0%)
3	23 (7.7%)
4	24 (8.1%)
5	45 (15.2%)

Unless otherwise indicated, values are expressed as the number of patients (%).